Precipitation Rate Estimation Based on Specific Attenuation

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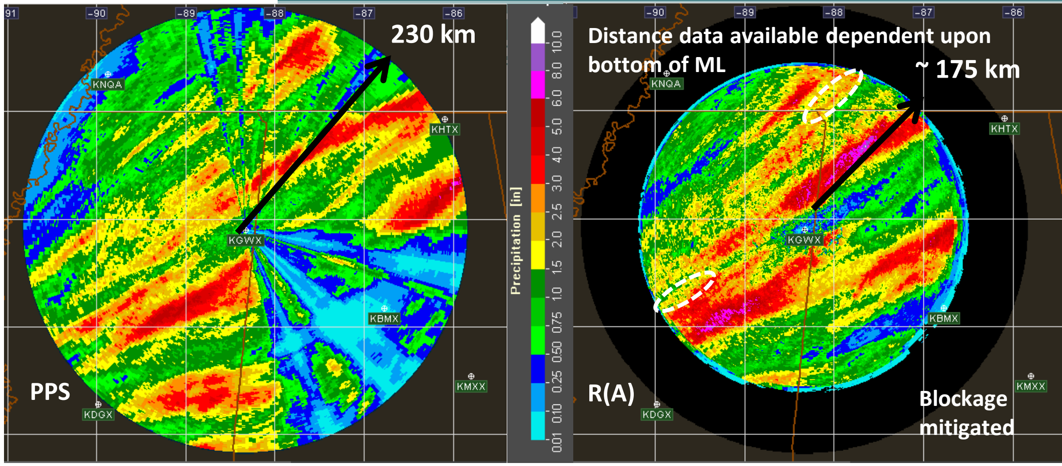

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Operational Radar QPE: A Short Review

- **Until 2010, radar QPE primarily consisted of the use of a single reflectivity to rain rate, or R(Z), relation to estimate precipitation amounts**
  - *Warm season: convective R(Z)often used…Cool season: list of R(Z)s available*
  - *Any R(Z) changes were forecaster initiated and applied to entire field of view*

- **Between 2010 - 2014, Dual Pol (DP) & MRMS QPEs transitioned to operations that automatically assigned a rain rate relation depending upon echo classification**
  - *Below [above] melting layer (ML), DP used R(Z,ZDR) & R(KDP) [R(Z)]*
  - *MRMS used multiple R(Z)s and applied Bright Band correction w/in & above ML*

- **Despite advances, need continues for rain relations less sensitive to microphysics**
  - *R(Z) relations sensitive to Z calibration & drop size distributions (DSD) changes*
  - *R(Z,ZDR) sensitive to calibration challenges*
  - *R(KDP) cannot capture all DSD variability and can be noisy*

- *Ryzhkov et al. (2014) and Wang et al. (2014) indicated good potential in using Specific Attenuation (A) to estimate rain*

Specific Attenuation 'A': Equations

- **'A'** defined by: $A(r) = \dfrac{Z_a^b(r)C(b,PIA)}{I(r_1,r_2) + C(b,PIA)I(r,r_2)}$ *where 'Z_a' is attenuated reflectivity*

Radar Radial

$\mathbf{Z_a(r_1)}$ $\mathbf{\Phi(r_1)}$			$\mathbf{Z_a(r)}$				$\mathbf{Z_a(r_2)}$ $\mathbf{\Phi(r2)}$

$$I(r_1,r_2) = 0.46b\int_{r_1}^{r_2} Z_a^b(s)ds$$

$$I(r,r_2) = 0.46b\int_{r}^{r_2} Z_a^b(s)ds$$

$$C(b,PIA) = \exp(0.23bPIA) - 1$$

where $PIA(r_1,r_2) = \alpha\left[\underbrace{\varphi_{DP}(r_2) - \varphi_{DP}(r_1)}_{\text{Total span of PhiDP along radial}}\right]$

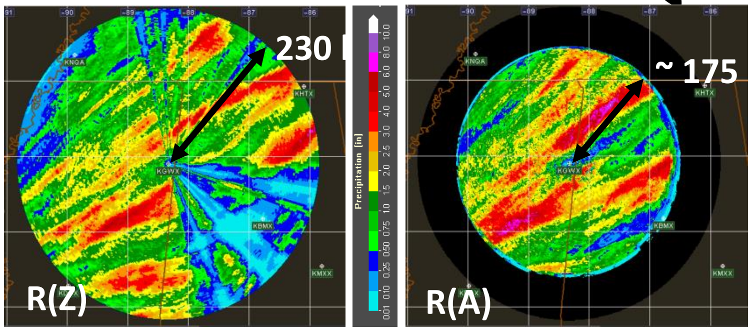
PIA => Path Integrated Attenuation

- Rain rates from **A** are calculated via: $R(A) = 1420.0A^{1.03}$

where the constants were optimized for S band radars

*Parameter '**α**' must be estimated in order to calculate **A** fields*

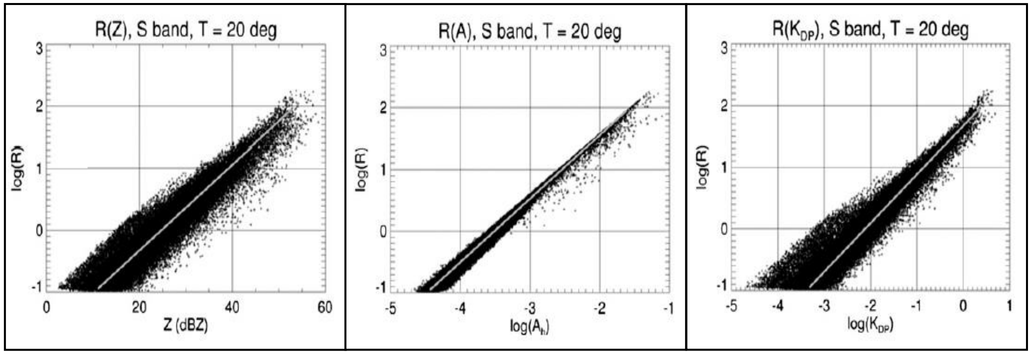
Advantages of Using Specific Attenuation for QPE



1. Immune to calibration, partial blockage, attenuation, & wet radome challenges

2. Higher spatial resolution than $R(K_{DP})$ estimates

3. Less sensitive to the DSD variability than $R(Z)$ and $R(K_{DP})$



CAVEATS

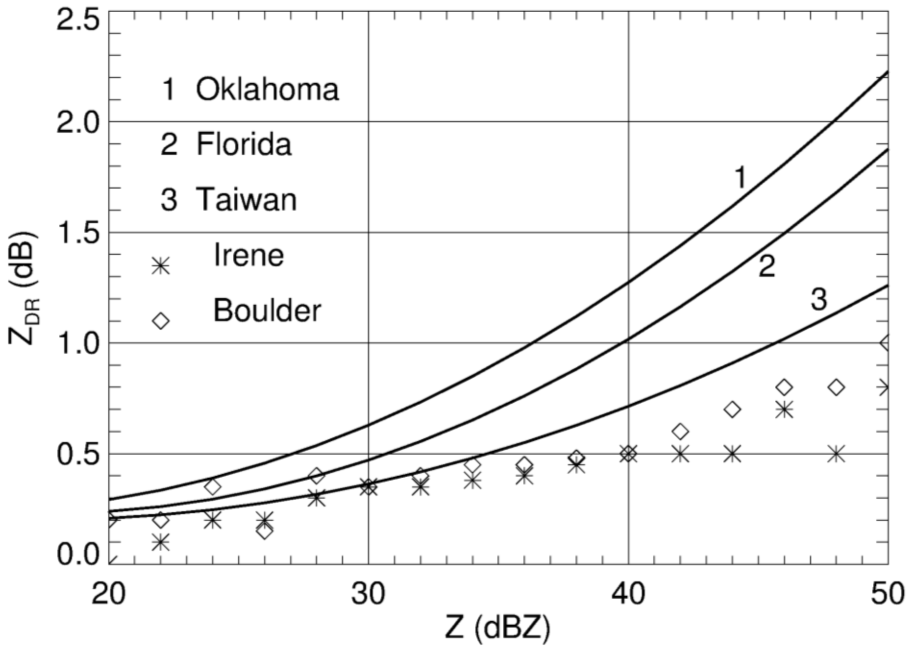
1. Must use R(Z) within/above ML and when $\Delta\phi_{DP} < 5°$

2. Use R(KDP) in hail cores

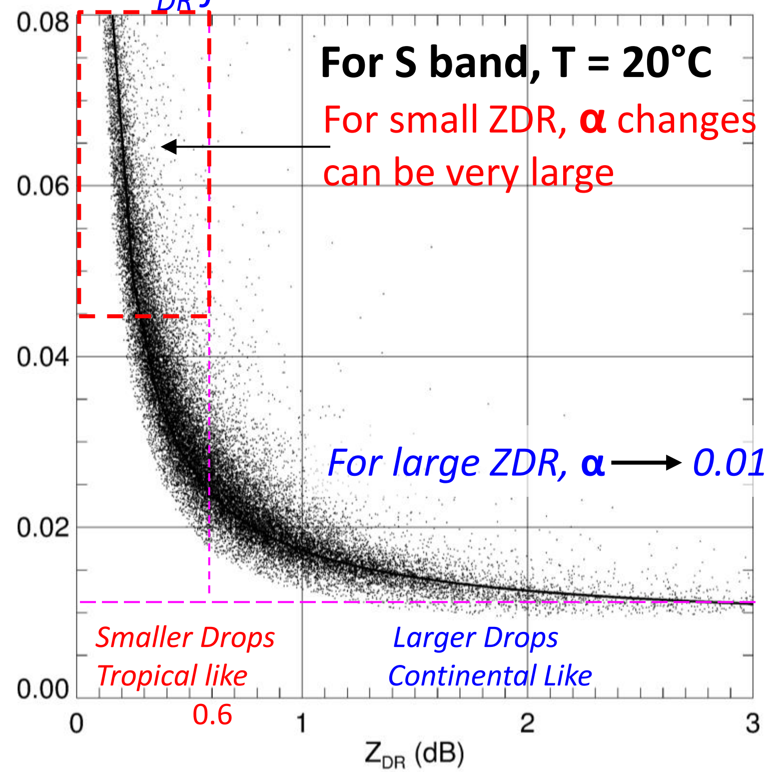
Physical Significance of Parameter *Alpha*

- Previous case study work suggested ***α*** :
    - *Higher (lower) concentrations of smaller (larger) raindrops generally lead to higher (lower) alpha values*
    - Hence, ***α*** related to the type of rain regime (Tropical vs Continental)

Concept of the "Z_{DR} vs Z slope" to identify dominant rain type



α *vs Z_{DR} from disdrometer simulations.*



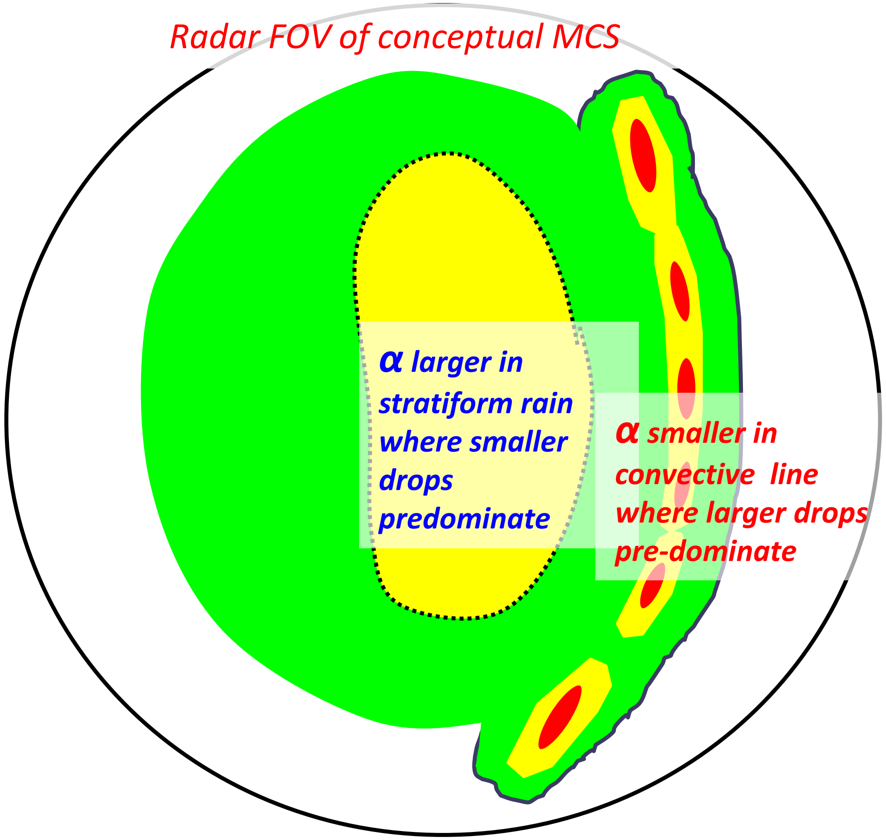
Estimating the Parameter '*α*'

- **Within a precipitation event, alpha can vary considerably (see right)**
  - *Alpha smaller (larger) in convective (stratiform) rain*

- **Three options considered in estimating Alpha:**
  - *Assume fixed alpha throughout event*
  - *Estimate alpha for radar field of view (FOV)*
  - *Estimate alpha via radar echo classification of precipitation (convective or stratiform)*

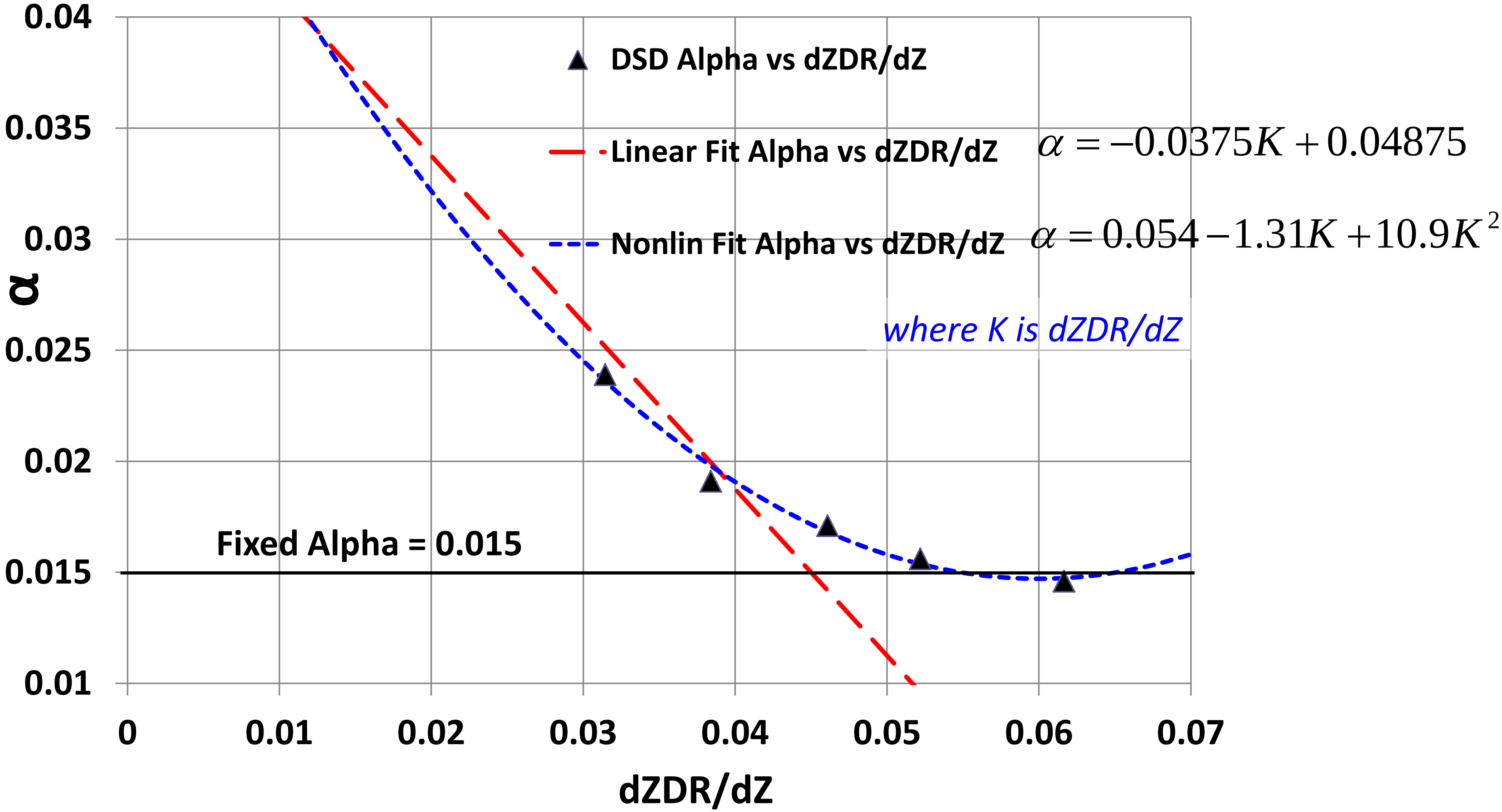
- **1st two options assume a spatially uniform alpha for radar FOV; initial tests indicated that:**
  - *PhiDP span & radial Z enough to modulate **A** fields to allow relevant R(A) rates*

- **3rd option was attempted but results very similar to option 2 (likely need more sophisticated classification methodology to improve results)**
  - *Hence, we calculated rain rates from A fields where alpha estimated via options 1, 2*



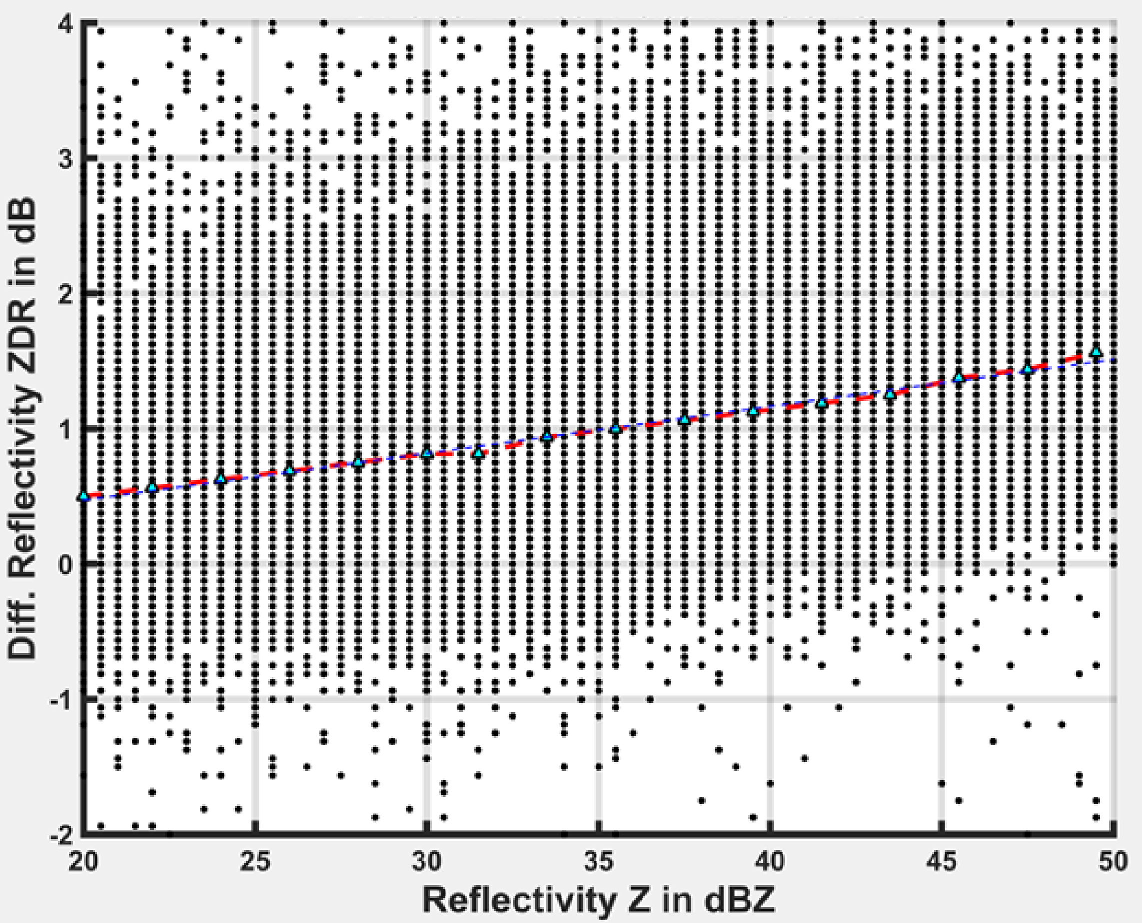
Estimating the Parameter ‘α’

- ***α vs dZDR/dZ from disdrometer simulations (black triangles), with non-linear (blue) and linear (red) fits shown***
  - *Linear fit approximates well if use alpha lower (upper) limit of 0.015 (0.040)*
  - *Non-linear fit still under evaluation*



Estimating Parameter ‘α’: *Real Time Estimates*

- **For each 0.5° tilt, ZDR/Z pairs within pure rain collected**
  - *Data is binned and medians calculated for bins between Z = 20 and 50 dBZ*
  - *Linear fit of medians made for bins meeting following conditions:*

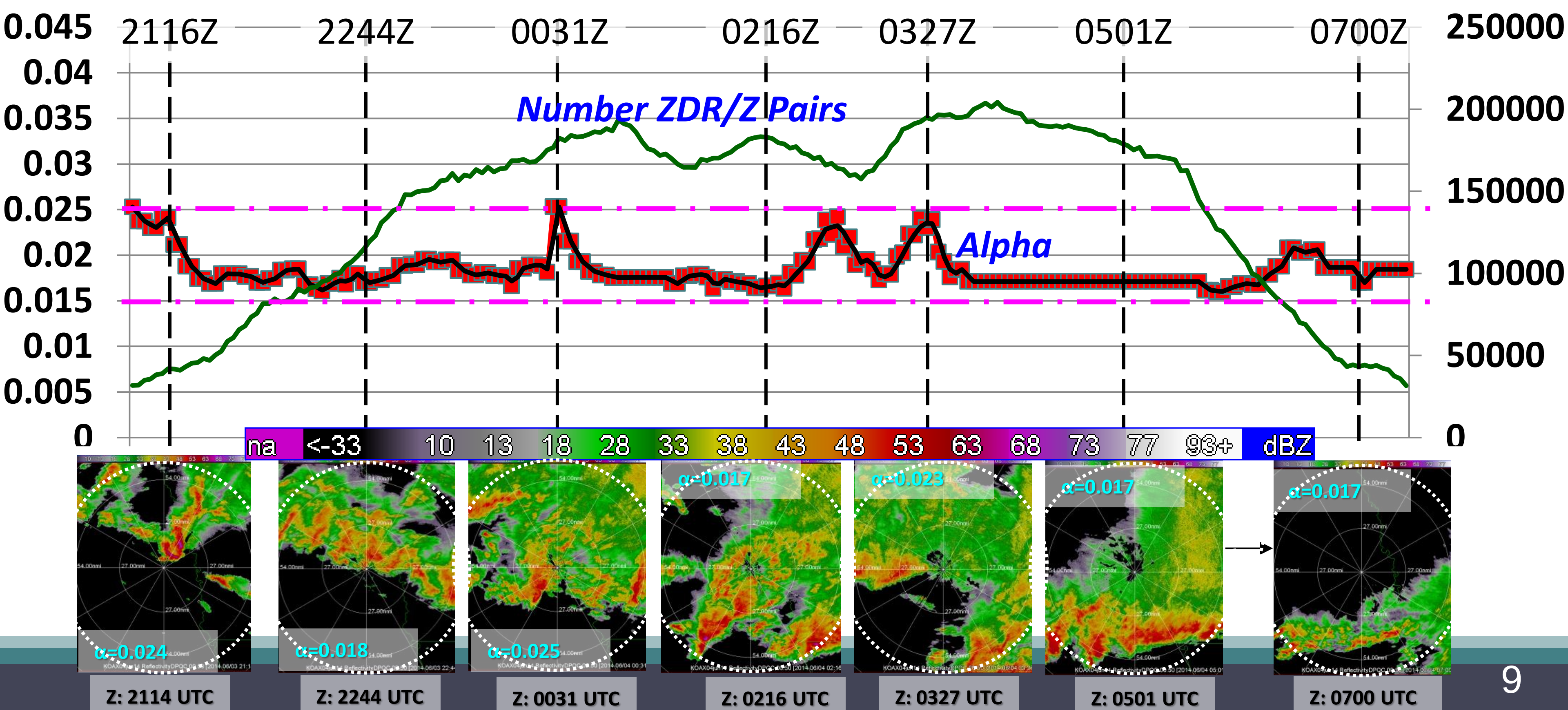


ZDR/Z Pair Thresholds:

- *Pairs collected for RhoHV > 0.98 & -4.0 < ZDR < 4.0 dB*
- *Total pairs > 30000*
- *Z Bin Total > 1000 before median calculated*
- *At least 6 bins must meet above requirement before regression fit made to ZDR/Z pairs*
- *If no fit, mean of previous 10 estimates taken*

Alpha vs. Time

- **Alpha vs time for Continental and Tropical regime precipitation events**
  - *Continental: Severe hail and wind storms over KOAX, 3 – 4 June 2014* **X**
  - **Tropical: Hurricane Matthew, KCLX, 7 – 8 October 2016**



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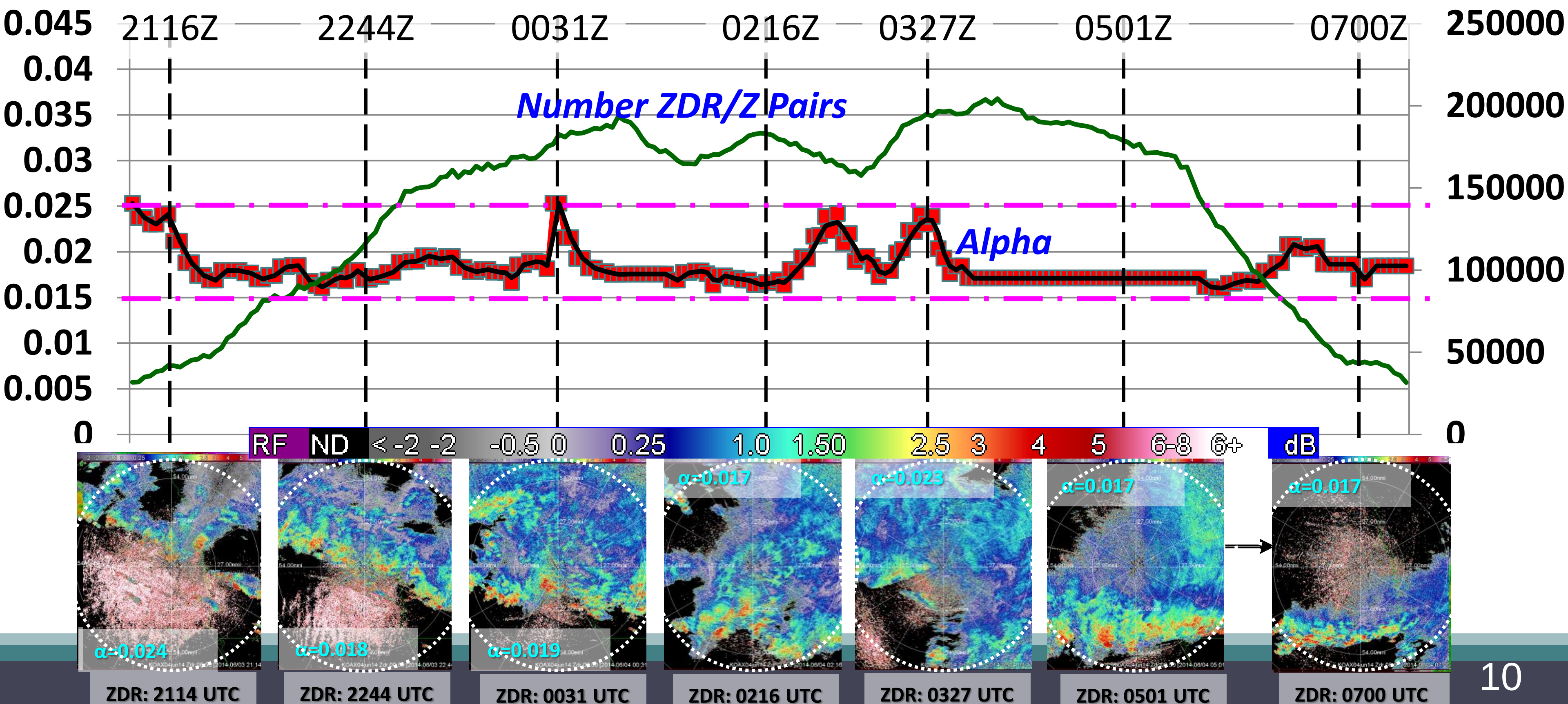

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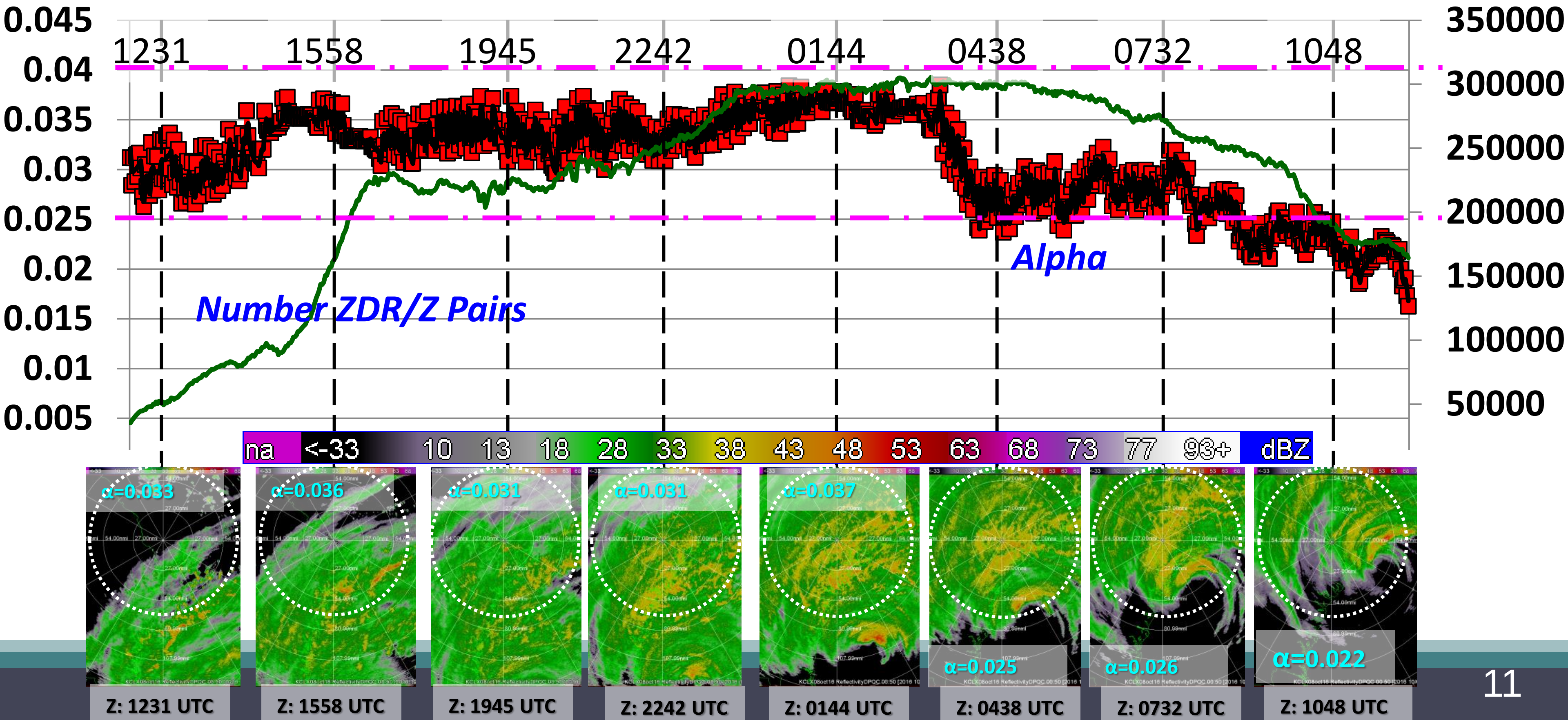

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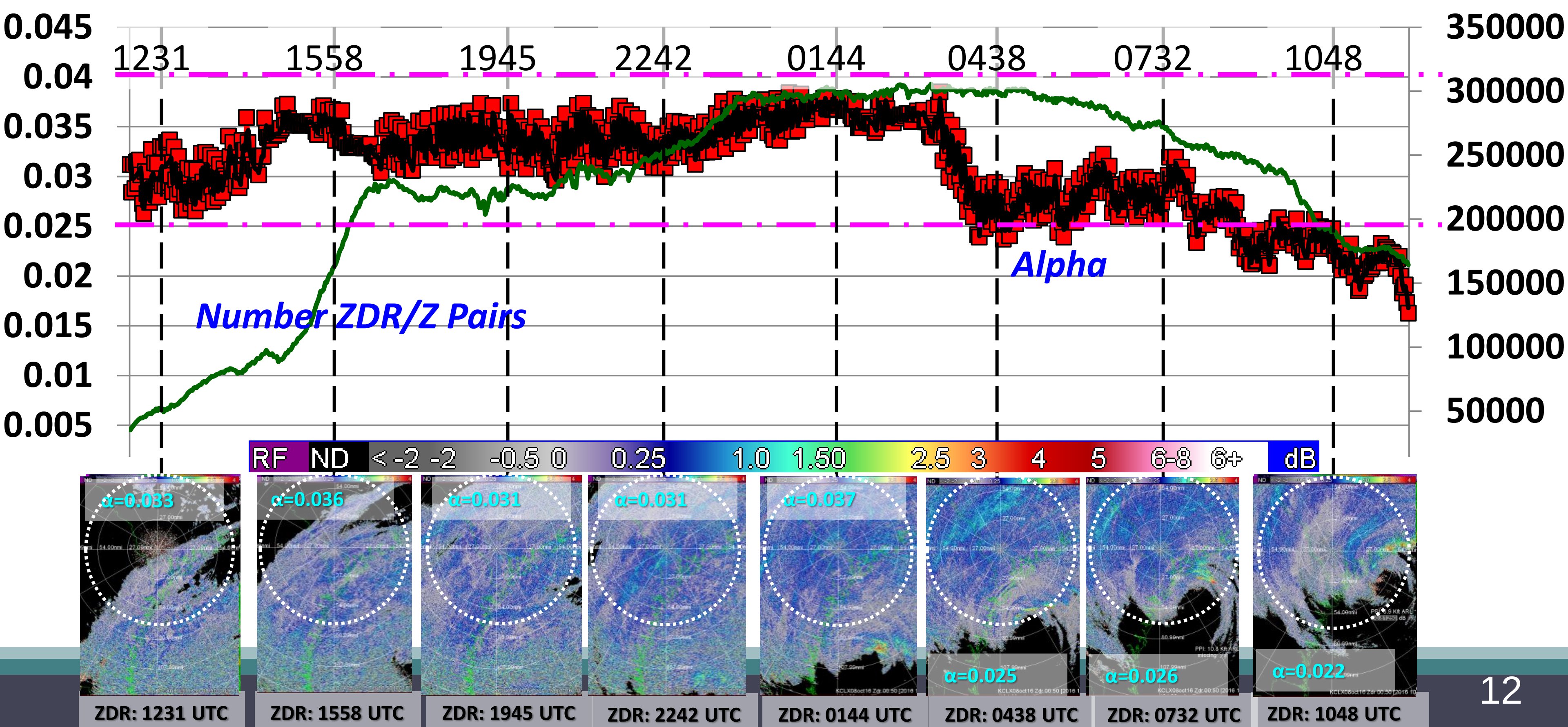
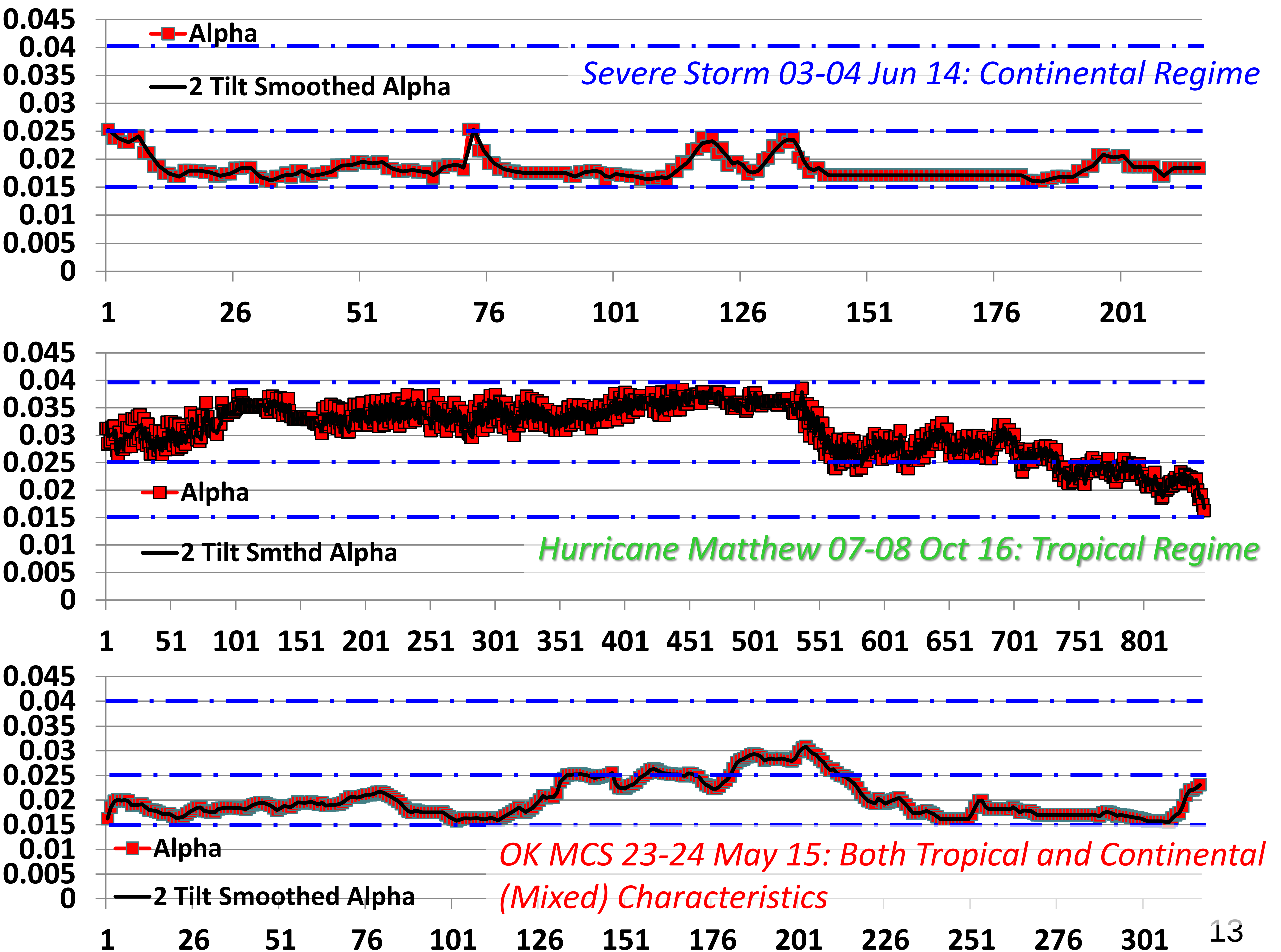
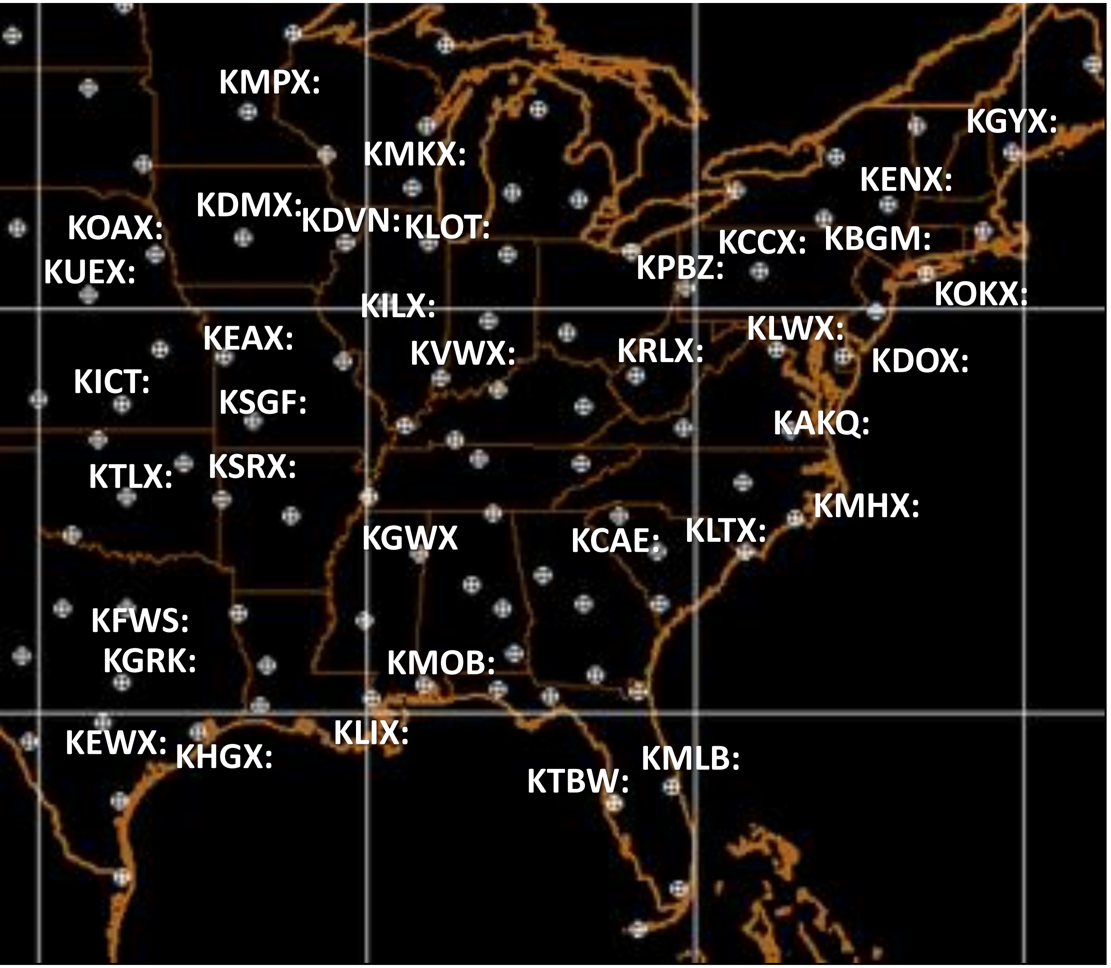




Alpha
2 Tilt Smoothed Alpha
Severe Storm 03-04 Jun 14: Continental Regime
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
1
26
51
76
101
126
151
176
201
Alpha
2 Tilt Smthd Alpha
Hurricane Matthew 07-08 Oct 16: Tropical Regime
1
51
101
151
201
251
301
351
401
451
501
551
601
651
701
751
801
Alpha
2 Tilt Smoothed Alpha
OK MCS 23-24 May 15: Both Tropical and Continental (Mixed) Characteristics
1
26
51
76
101
126
151
176
201
226
251
276
301

VALIDATION



- We calculated R(A) + R(KDP) rain rates by: 1) assuming a fixed alpha for duration of precipitation event; and 2) estimating alpha for every 0.5° tilt
- For validation we used data from 36 WSR-88D radars on 44 different calendar days during the 2014 – 2016 warm seasons
  - *Radars chosen spanned a large portion of the Eastern US*
  - *Most cases comprised of MCSs with tropical, continental or mixed rain regime characteristics*

- R(A) estimates were used below ML while R(KDP) used in strong convection (Z > 50 dBZ)
  - *Farthest estimates made from radar was 120 km to avoid the ML; however, we used RhoHV, model & rawinsonde data manually and adjusted a handful of cases to values less than 120 km*

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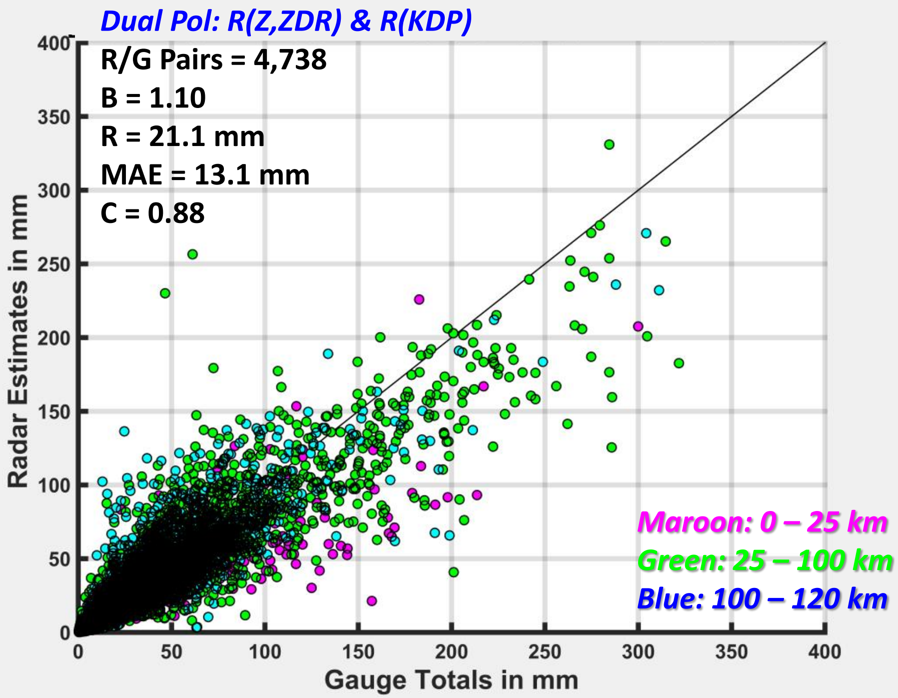
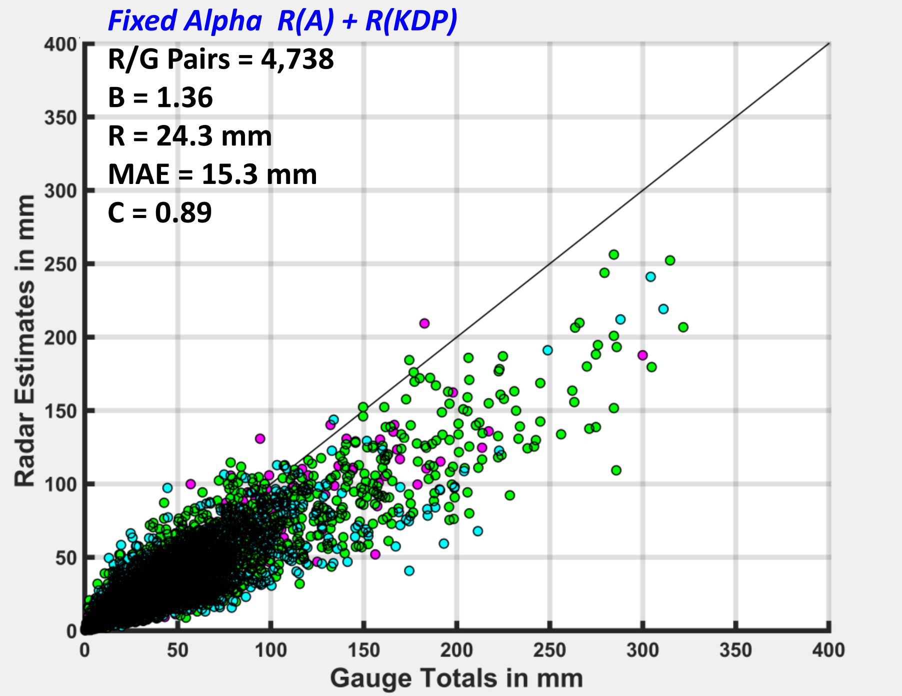
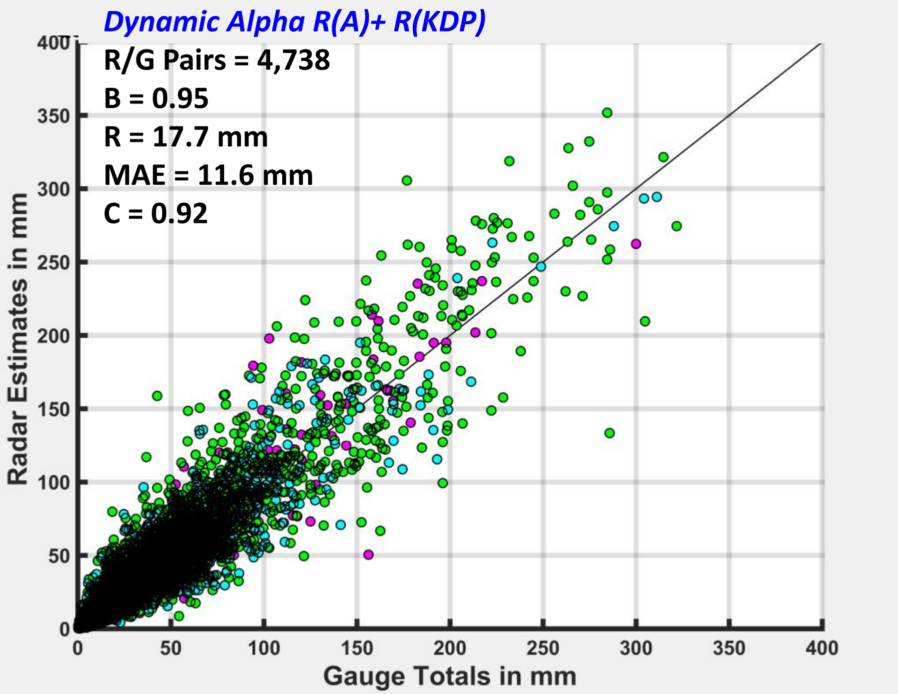
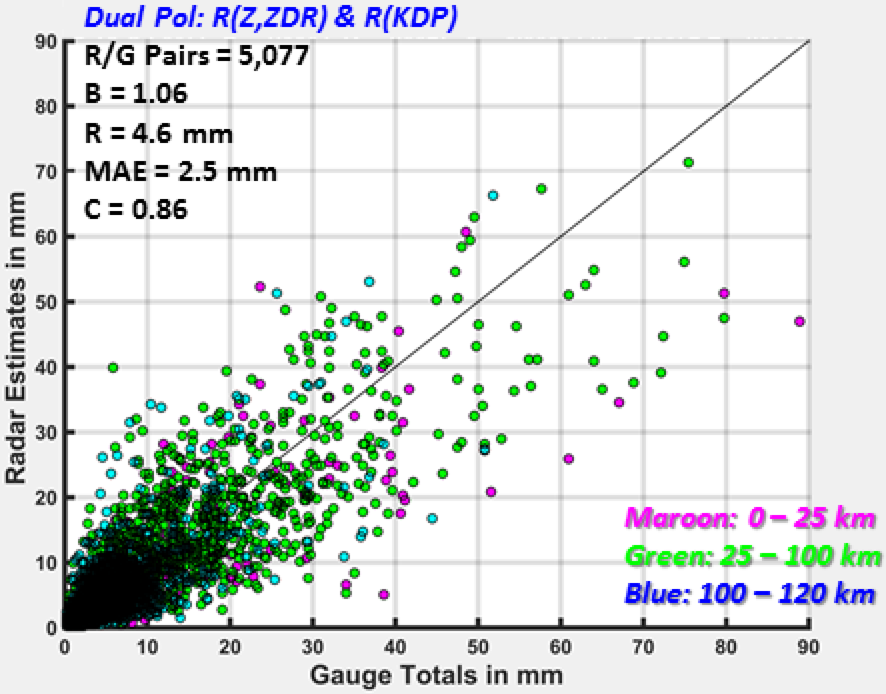


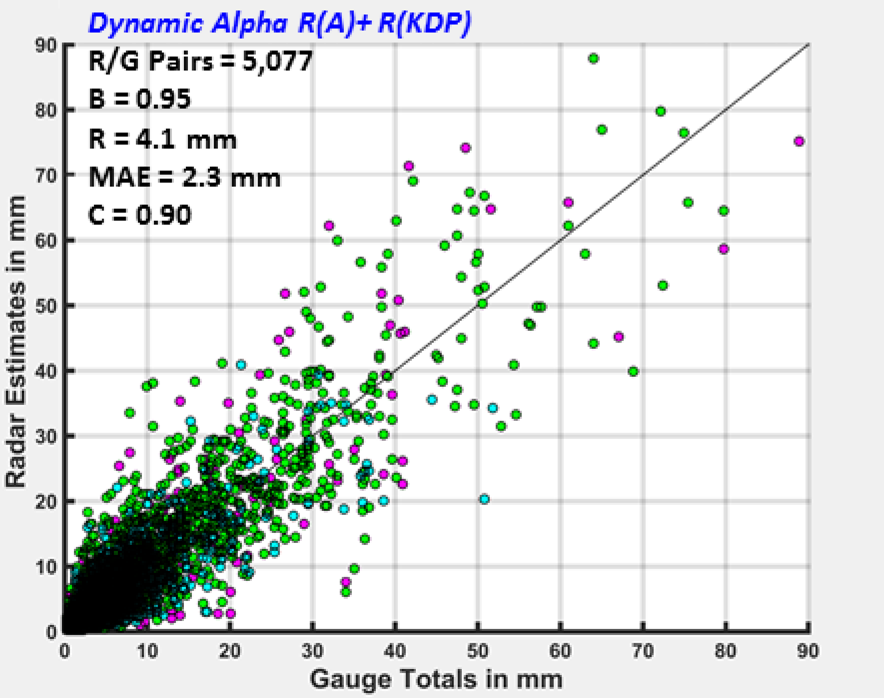




- 24-hr *Dual Pol (top left), Fixed (top right) & Dynamic Alpha (top right) QPE* to QC'd CoCoRaHS/automated gauges for ***all cases***
  - Fixed alpha QPE causes significantly higher errors/underestimate bias

- Despite known alpha variability within precipitation events, Dynamic Alpha performed better than Dual Pol, *especially for* gauge totals > 150 millimeters

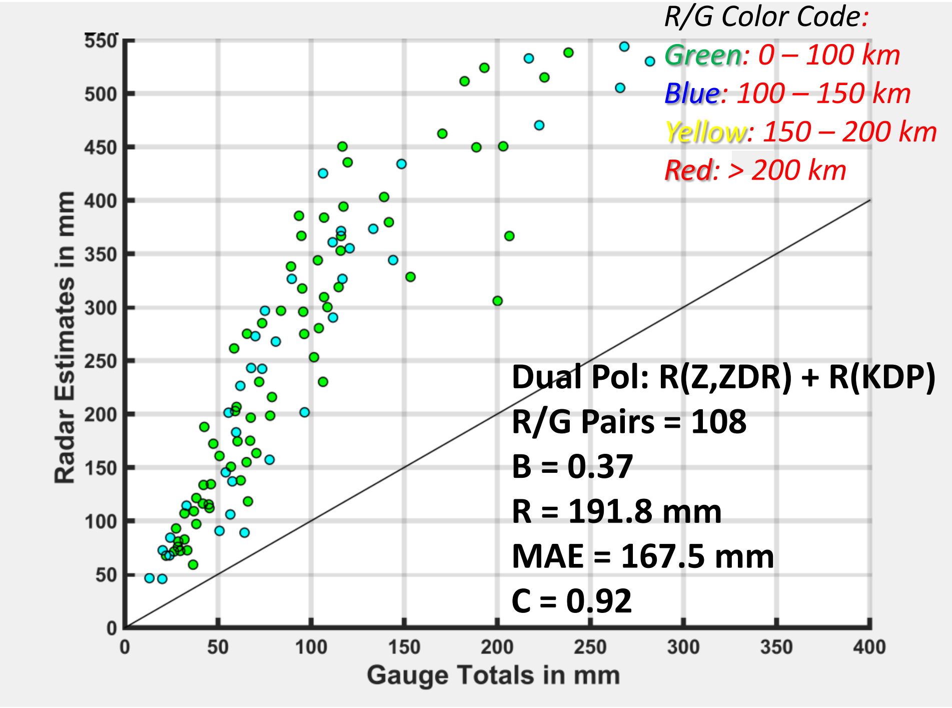


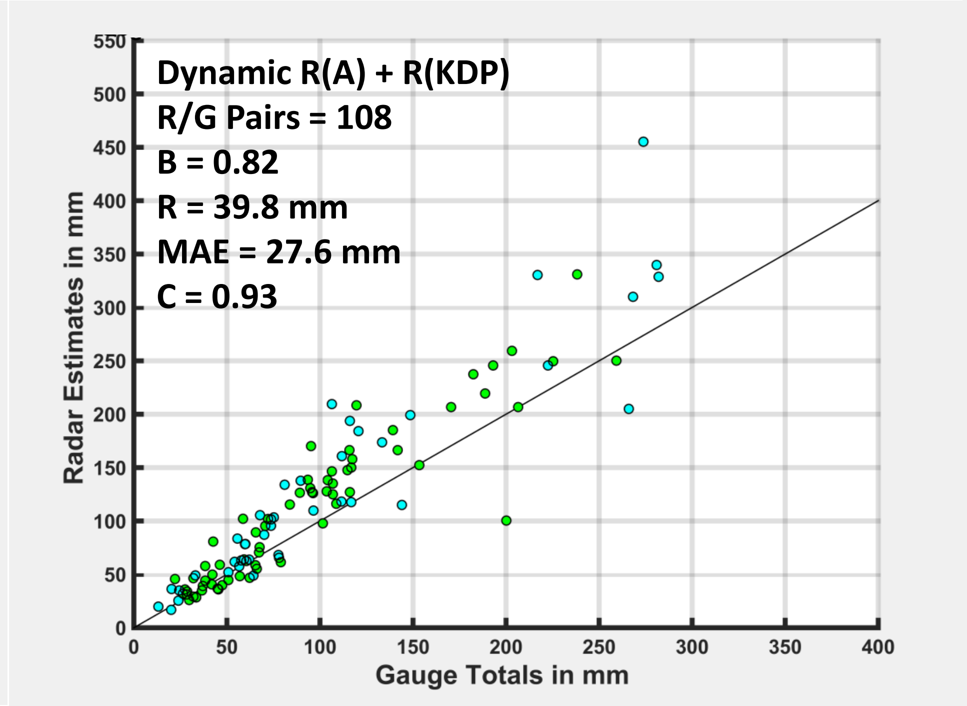


- Comparison of 1-hr *Dual Pol (top left), Dynamic Alpha (bottom left) QPE* estimates to quality controlled CoCoRaHS & automated rain gauges for ***thirteen cases only***

- Differences were more subtle however there was higher correlation and overall less scatter for the R(A) + R(KDP) QPE
  - *Noteworthy was the performance of the new QPE for higher rainfall totals (G > 40 mm)*

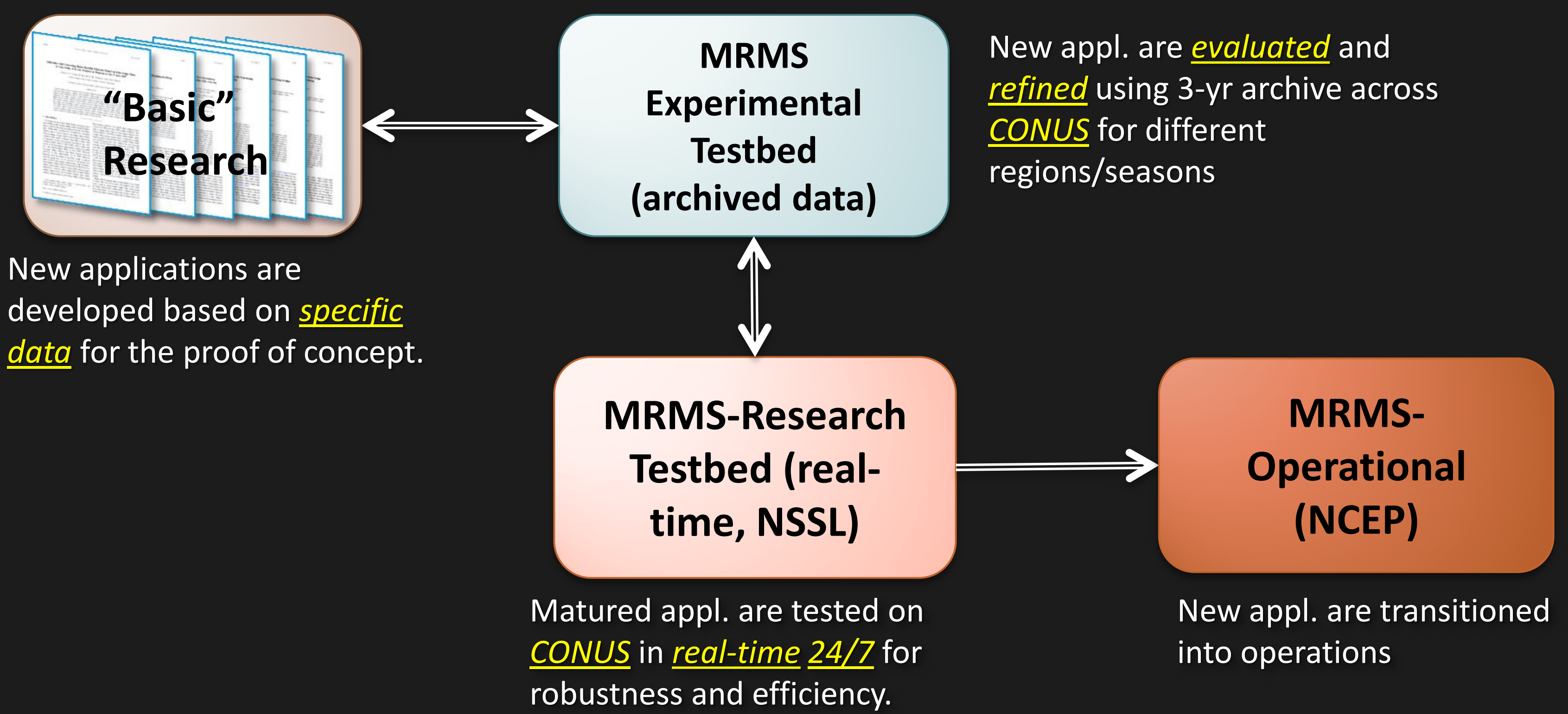
MITIGATION OF ZDR/Z MISCALIBRATION





- *24-h acc. operational Dual Pol (top left) and Dynamic R(A) (top right) estimates vs. QC'd. 1200 UTC CoCoRaHS & HADS gauges for period ending 12 August, 2016*
- *Data from KLIX radar in New Orleans, LA; during rainfall event, ZDR (Z) for radar was over 1 dB low (~0.75 dBZ high) resulting in very high 24-h accumulations*
- *Despite ZDR/Z calibration challenges associated with Dual Pol, the new QPE substantially reduced errors*

- The evolution of this new technology followed the procedures (see image below) developed for the MRMS testbed to transition research into operations
    - Basic research on Specific Attenuation rainfall estimation led to proof of concept (Ryzhkov, et al. 2014, Wang et al. 2014)
    - Prototype algorithm developed and tested using archived data
    - Earlier this year, algorithm imported into MRMS Research Testbed for evaluation of precipitation estimation below melting layer/R(Z) within and above melting layer
    - Goal is to transfer first version of algorithm to operations late this year



Summary

- **R(A) +R(KDP) algorithm, using methodology of Ryzhkov et al. (2014), tested on large dataset**
  - *44 calendar days/36 S-band radars examined during 2014-2016 warm seasons*

- **Algorithm exhibited better performance than operational Dual Pol QPE**
  - *Algorithm estimates exhibited less bias/less scatter than Dual Pol*
  - *Use of ZDR/Z slope to estimate* ***α*** *avoids ZDR & Z miscalibration issues*
  - *Technique also mitigates partial beam blockage effects*

- **Parameter 'alpha' key to calculating Specific Attenuation (A) fields**
  - *Parameter sensitive to rain regime; alpha values are higher (lower) for tropical (continental) rain events*

- **Work continues on algorithm refinement to further improve performance in wide range of rain types and climate regimes:**
  - *Improving the methodology used to estimate the ZDR/Z slope for Linear Alpha*
  - *Expanding algorithm to include Alpha estimates made using the Non-Linear equation*
  - *Refining R(A) algorithms capability to automatically determine presence of melting layer*
    - *Current version running in real-time in MRMS Research Testbed*

Summary

- **Using the MRMS infrastructure allows researchers to:**
  - *examine large numbers of cases in a relatively short period of time*
  - *efficiently test code, developed from basic research, in real time across the entire U.S.*
  - *evaluate performance in different geographical regions (e.g. east vs west) and seasons (warm vs cool)*

Robust testing and validation through MRMS allows for rapid improvement of new technology leading to a smoother transition into operations

- Where to find MRMS technical documents
  - WDTD Training Web-Site: http://www.wdtd.noaa.gov/courses/MRMS/
  - VLAB MRMS Community: https: //vlab.ncep.noaa.gov/group/mrms/wiki

QUESTIONS

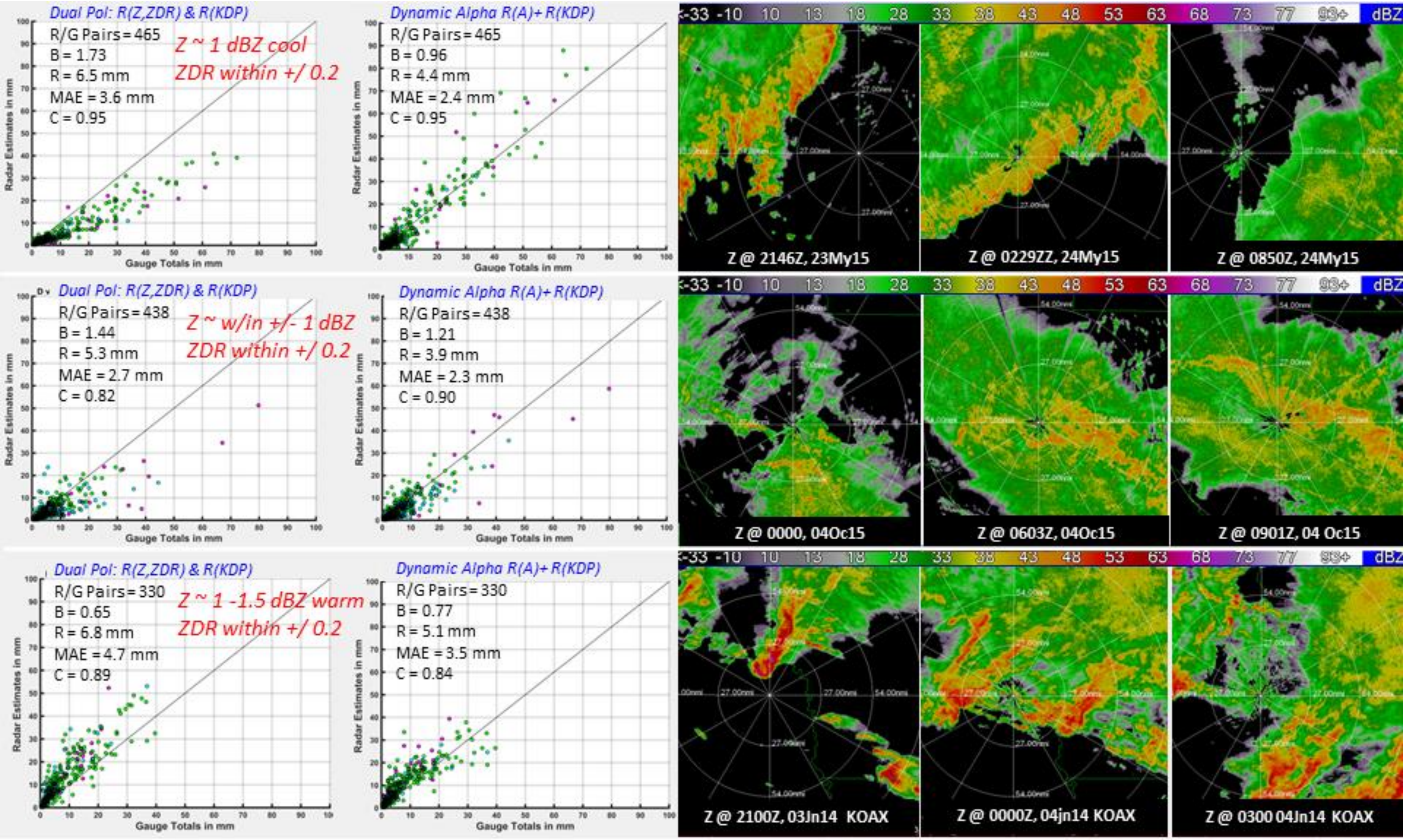
If you have questions regarding MRMS please contact either
Steve Cocks (stephen.cocks@noaa.gov) or Jian Zhang (jian.zhang@noaa.gov)

REFERENCES:

Ryzhkov, A., M. Diederich, P. Zhang, C. Simmer, 2014: Potential Utilization of Specific Attenuation for Rainfall Estimation, Mitigation of Partial Beam Blockage and Radar Networking., J. Atmos. Oceanic Technol., 31, 599-619

Wang, Y., P. Zhang, A. V. Ryzhkov, J. Zhang, P. L. Chang, 2014: Utilization of specific attenuation the tropical rainfall estimation in complex terrain., Journ. Hydromet., 15, 2250-2266

HOURLY PERFORMANCE: SOME SELECT CASES



- **1hr QPE vs gauges (left 2 columns) & Z (right 3 columns) for 23-24 May 15 (top), 03-04 Oct. 15 (middle) and 03-04 Jun. 14 (bottom):** *R(A)+R(KDP) exhibited better performance than Dual Pol although overestimate bias present in some convective events (bottom row)*

MRMS INTEGRATION

- Image below shows how prototype algorithm precipitation estimates integrated with R(Z) estimates within MRMS